An environmental sanitation problem for the new atomic age may be created by the discharge of radioactive byproducts of nuclear reactions into surface streams. A first anticipatory step is to measure the effects, however slight, of such contamination.

Effects of Low-Level Radioactivity in the Columbia River

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THE Public Health Service conducted water quality studies on the Columbia River over a period extending from mid-1951 to mid-1953. Presented here is a brief summary of the general aspects of these studies, followed by a more extended account of the radiobiological phases.

Initiation of Studies

In the accumulation of data to be used for pollution control programs throughout the Nation, it was found that information was needed on the Columbia River from at least two standpoints: (*a*) for determining the effects of impoundments, several of which were proposed or under construction, and (*b*) for determining the effects of radioactive wastes on stream quality.

The construction of impoundments encourages the development of industrial sites, especially where additional power becomes available, and of recreational areas. In semiarid regions, such as the Columbia River Basin, the increased availability of water for irrigation brings about the development of agricultural areas. Hence, the waters must serve a variety of interests, and in many cases the interests of one group are in conflict with those of another. In order that all interests may be served effectively, basic water quality inventories are necessary.

From the standpoint of the effects of radioactivity, the interests of health, defense, industry, and agriculture were recognized. As the use of radioactive isotopes continues to expand, the responsibility of public health officials for protecting the general population against harmful effects of ionizing radiation will broaden.

The Atomic Energy Commission and the General Electric Co., the present operating contractor at Richland, Wash., have a real interest in using the Columbia River as a source of industrial water supply and also for disposal of

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mildly radioactive cooling water from the nuclear reactors. They have, therefore, an understandable concern as to the possible effects of proposed multiple impoundments of the river for irrigation and power projects, lest changes in the characteristics of the stream have an unfavorable influence on plant operations. In addition, the joint interests of the States of Washington and Oregon as to the present and future uses of the river were an important consideration.

A continuous program for controlling the discharge of radioactive wastes to the Columbia River has been in effect since the start of plant operations in 1944. This program, carried out by the operating contractors at the Hanford Works, has included not only the control of waste discharges but also the monitoring of the river within and adjacent to the AEC reservation.

Objectives

The principal objectives of the studies, therefore, were to determine (*a*) the water quality characteristics of the stream prior to impoundment and (*b*) the effects of radioactivity on the physical, chemical, and biological characteristics of the stream. The studies also provided data which can be used to establish objectives for comprehensive water pollution control programs. The field work was correlated with the continuous monitoring and research activities of the General Electric Co. at the Hanford Works.

General Procedures

Most of the work was confined to the area between Priest Rapids and Paterson, Wash., a section which includes the Hanford Works and the McNary Reservoir. The latter is an impoundment which was placed in operation in late 1953. Limited studies were also made in Roosevelt Lake, Bonneville Reservoir, and the areas around Portland and Astoria, Oreg., to obtain information on existing impoundments and to determine the persistence of radioactivity to the mouth of the river.

In the Priest Rapids-Paterson section, shown in figure 1, three sampling ranges were located well above the Hanford plant area to serve as control points. Other ranges in this section were located so as to detect the influence of the plant effluents and other variables, such as tributaries, downstream cities, and impoundments. At each range several types of biological samples were collected in the shallow regions, and water samples were collected at 3 to 10 points across the stream. A mileage index system was used to denote a sampling range or cross section; the designation C–362, for example, indicates a sampling point 362 miles above the mouth of the Columbia River.

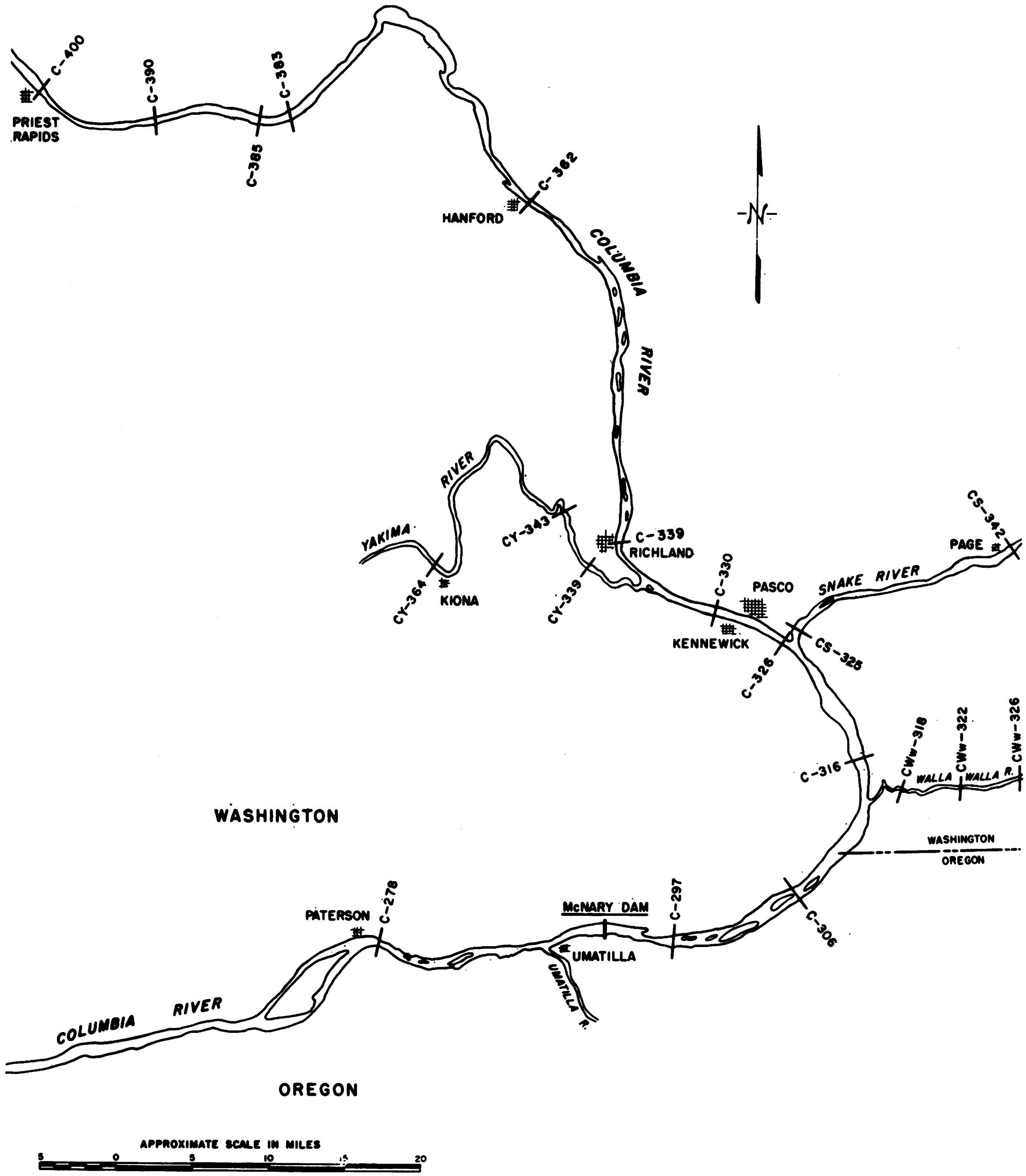
The routine physical and chemical examinations included determinations of turbidity, temperature, dissolved oxygen, ammonia, nitrites, nitrates, phosphates, sulfates, chlorides, pH, and total alkalinity. Mineral analyses were made for the elements considered necessary for plant and animal metabolism, as well as for components which might be toxic. Among these were calcium, magnesium, iron, manganese, zinc, and copper. Bacteriological studies were limited to the determination of coliform MPN.

In the biological studies, quantitative and qualitative samples of plankton, filamentous algae, bottom animals, and fish were collected. The sampling methods were those used in conventional stream surveys. Plankton was quantitatively determined by centrifuging and counting the organisms in a Sedgwick-Rafter counting cell. Bottom animal samples were collected in a square-foot riffle sampler and identified, and the numbers and weights of the various organisms were obtained. Fish were collected in seines and gill nets, and the relative abundance of the various species noted. Observations of spawning activity were made on some species of fish.

Effects on Stream Characteristics

The Hanford plant effluents had no definite measurable effects on any of the physical or chemical characteristics of the Columbia River. Although some of the effluents were thermally hot, the magnitude of the flow in the river was such that there was no general temperature change. On several occasions, slight temperature increases were noted in the area near the

Figure 1. Sampling ranges in the Priest Rapids-Paterson section of the Columbia River, the principal area studied in 1951–53.



effluent outlets. Changes in river flows and the influx of major tributaries did have some effect on the physical and chemical characteristics. However, physical or chemical conditions that would be considered detrimental to aquatic life were not found at any time during the survey.

For many years, the hydrological, physical, and chemical characteristics of the river have followed a definite seasonal pattern. High flows of 300,000 to 400,000 cubic feet per second generally occur between May and July. The most turbid water reaches the Hanford area in late April or May. During the rest of the year the flow is generally about 50,000 to 60,000 cubic feet per second, and the turbidity is less than 7 p.p.m.

Coliform counts in the Columbia River varied from less than 3.6 to 4,600 MPN per 100 ml. of water. Population centers and tributaries were principally responsible for these variations.

The Hanford plant effluents had little or no effect on numbers and species of river organisms. The variety and abundance of most river organisms were similar above and below the manufacturing areas. Where any differences occurred, they could be attributed to the seasonal variation or the influence of the relatively more turbid, warmer tributaries.

Radiobiological Studies

Although many radioactive wastes and coolants are produced in the manufacture of plutonium at the Hanford plant, the only large effluent to enter the Columbia River directly results from the cooling of the nuclear reactors. The radioactivity is induced by the neutron bombardment of dissolved and suspended materials in the cooling water. The passage of these materials through the atomic pile is held to a minimum by conventional pretreatment of the coolant. The radioisotopes produced in the coolant are principally beta-particle emitters with short half-lives; consequently, retention of the coolant in large open tanks, which provides time for some natural decay, substantially reduces the amount of radioactive material that enters the river.

Water and biological samples, collected weekly or biweekly, were prepared for radiological measurement by reducing the sample to a minimum size for insertion into a Geiger-Müller tube, end-window counter. For most solid samples, reduction was accomplished by digesting the organisms in nitric acid and ashing the digestate in a muffle furnace. The residue was then plated on a 1-inch stainless steel planchet and counted for 5 to 15 minutes. The raw count was corrected for decay, geometry, scatter, and absorption, and the results were reported in terms of microcuries per gram of original tissue.

Average Levels of Radioactivity

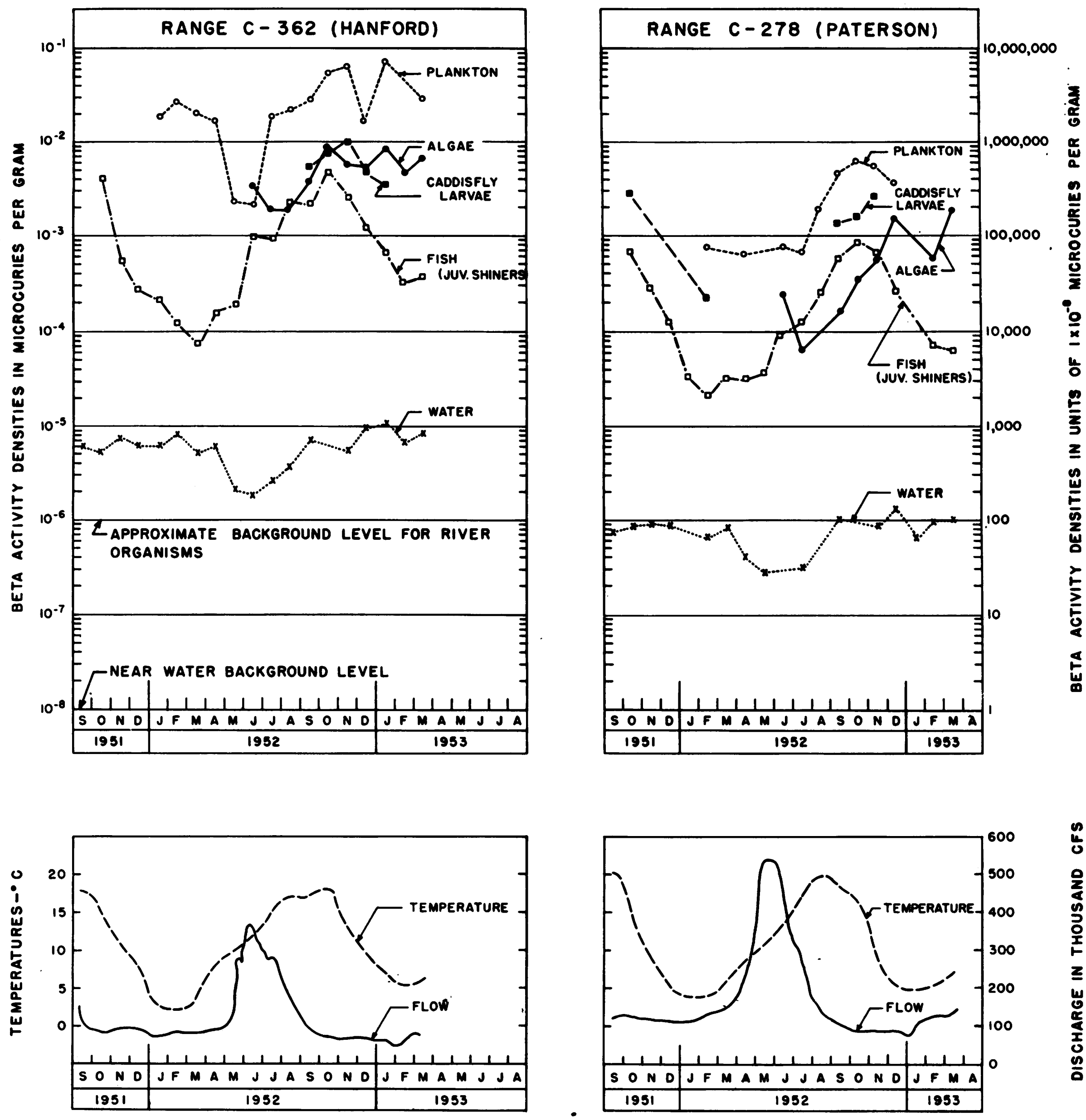
The average gross beta activity density of the water and of the various river organisms (plankton, filamentous algae, caddisfly larvae, and fish) at two of the ranges is given in figure 2. Range C–362, which showed the highest average results, is located just below all nuclear reactors, and range C–278, which showed the lowest average results in the principal study area, is the last range downstream in this section. It is evident from these data that the river organisms concentrate radioactive materials to a considerable degree, up to nearly 10,000 times the total beta activity in the river water. River flows and temperatures at the two ranges are also given in figure 2, for correlation with the radioactivity density.

The accumulation of radioisotopes by aquatic organisms followed a definite pattern. Plankton (mostly phytoplankton) and filamentous algae, which absorb nutrients directly from the water, showed the greatest concentration of radioactive materials. The next greatest concentrations were found in bottom animals, which feed on these organisms; the next, in juvenile fish, which feed principally on the bottom animals. At the end of the chain were the adult game fish, which feed on the juveniles. There were, of course, some deviations from this pattern. Fish that feed directly on plankton and algae reflected higher values in individual samples, whereas crayfish, which possibly feed on dead fish or other animals, reflected lower values.

Levels of radioactivity in plankton and algae were directly dependent upon the radioactivity levels in the water, which were in turn dependent upon river flows and the amount of radioisotopes released into the stream. Values were highest at low water stages, but they were not influenced greatly by changes in water temperature.

Radioactivity levels in most aquatic animals varied with the volume and radioactivity density of the food they consumed. The volume of food consumed depended on their metabolic rate, which in turn depended upon water temperatures. Values for bottom animals were highest at low water stages and high water temperatures. There was a decrease in radioactivity in the organisms with a decrease in water

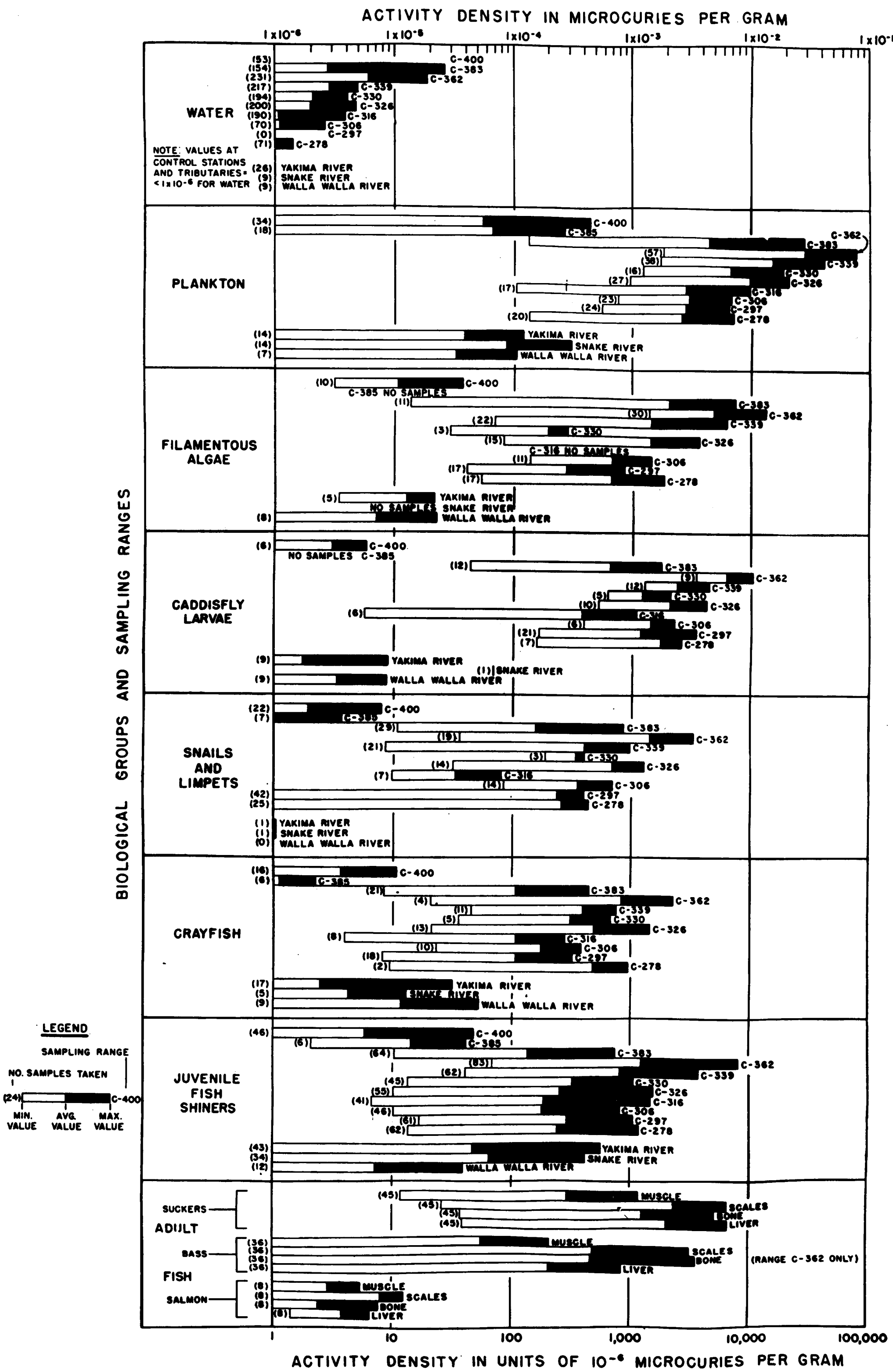
Figure 2. Seasonal variations in beta activity densities in the water and in various organisms of the Columbia River.



temperature, even though the radioactivity of the materials upon which these animals feed remained relatively high.

The decrease in radioactivity levels with a decrease in water temperature was most marked in fish. Some species, such as bass, which are known to stop feeding when water temperatures are low, showed very low radioactivity levels during the winter months in spite of the fact that there was little or no reduction in the radioactivity level of the water. The radioactivity levels in these fish rose rapidly with the resumption of conditions conducive to feeding even though radioactivity levels in the water were lower than previously observed because of increased river flows. In other species, such as suckers and whitefish, which evidently feed to some extent even during periods when the water is cold, the reduction in radioactivity was less pronounced. The radioactivity in adult sal-

Figure 3. Gross beta activity densities in water and in various organisms of the Columbia River.



mon, which migrate to this section of the Columbia River from June to October for spawning but do not feed, remained at very low levels.

Resident species which are feeding during this same period contained relatively large amounts of radioactive materials. Apparently, most aquatic animals concentrate radioisotopes of the type encountered in the Columbia River from the food they eat rather than by absorption through the skin or gills.

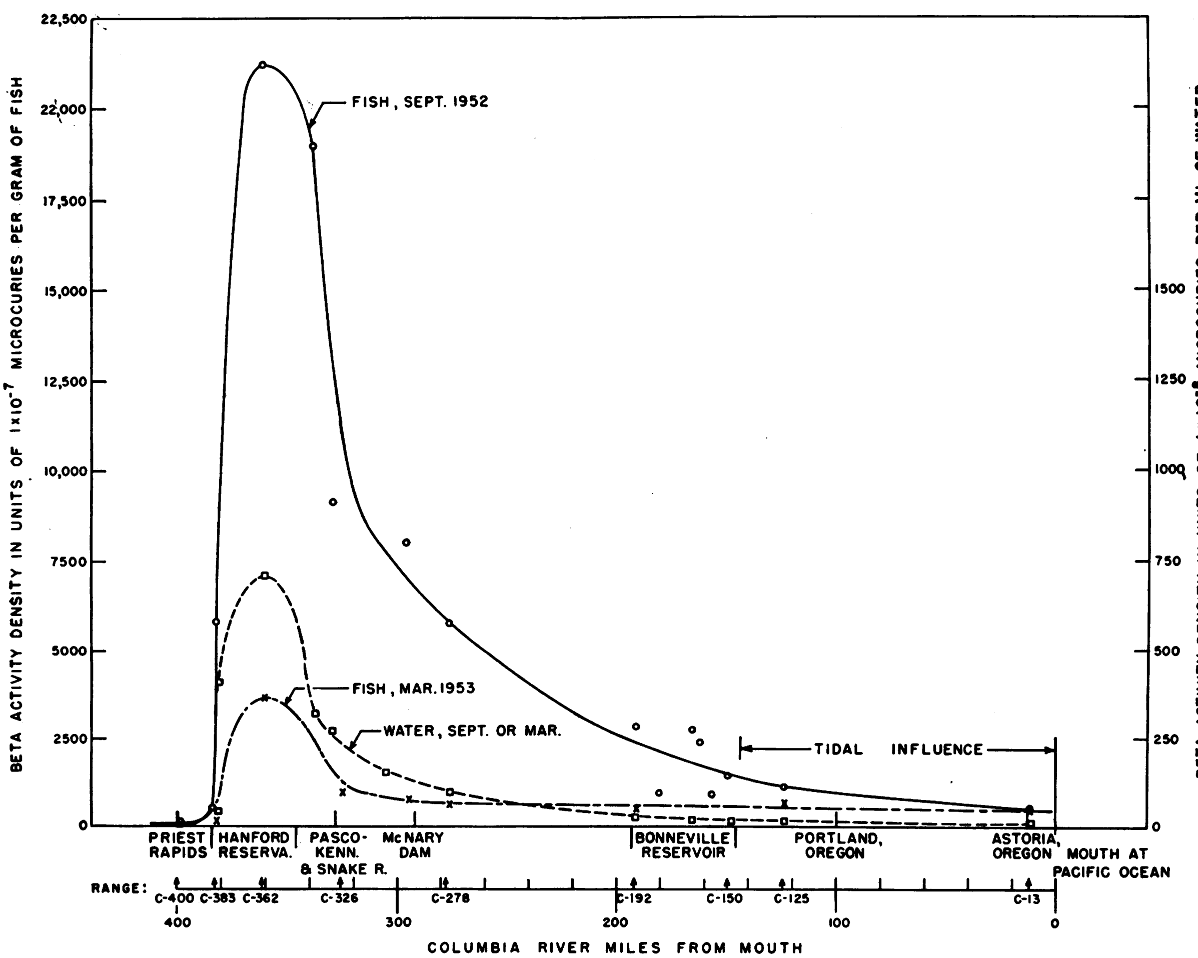
Types of Radioisotopes

The principal radioisotopes in the river water at range C–362 were such short half-life ones as copper–64 (12.8 hours), manganese–56 (2.6 hours), sodium–24 (15.1 hours), arsenic–76 (26.8 hours), and silicon–31 (2.8 hours). At this range, only about 1 to 2 percent of the activity was from the longer half-life phosphorus–32 (14.3 days), but at ranges farther downstream this radioisotope became more predominant percentagewise, since the activity from the short half-life radioisotopes had been reduced at a greater rate by natural decay.

The radioisotopes were selectively absorbed or concentrated differently by the various river organisms. Hatchery experiments with trout and salmon (*1*) have indicated that phosphorus–32 is concentrated in fish principally from food, whereas sodium–24 is absorbed directly from the water. Other radioisotopes may or may not be utilized by the various organisms, but small amounts may be taken into the body in food material.

At range C–362, most of the radioactivity in plankton was due to the short half-life radio-

Figure 4. Variation in average beta activity density in water and fish with location in the Columbia River.



isotopes mentioned previously. The proportion from the somewhat longer half-life phosphorus–32 was relatively small. Some of these short half-life radioisotopes may have been adsorbed on the siliceous diatom shells, which make up a large part of the river plankton. Farther downstream, a larger portion of the activity is caused by phosphorus–32.

The radioactivity in fish and other river animals was primarily from phosphorus–32, even near the areas where nuclear reactors are located. Since the percentage of phosphorus–32 in the water was low, it is evident that this radioisotope was concentrated many thousand times in some river animals. Only a very small part of the radioactivity in any of the river organisms was from radioisotopes with longer half-lives than phosphorus–32.

Variations in Radioactivity Levels

Owing principally to the decay of the relatively short half-life radioisotopes, the gross beta activity density decreased downstream. The activity levels in the river water and in the various river organisms at the different sampling ranges are shown in figure 3. The values decreased rapidly from Hanford (C–362) to Richland (C–339) and somewhat more gradually thereafter, a pattern followed with only slight variations in both the water and the river organisms.

The activity density of adult fish at one sampling range, C–362, is also given in figure 3. The values shown are the highest values for individual parts or organs of each species of fish. The activity density of scales, bones, and internal organs was about 10 times the activity density of the flesh and skin, the edible parts.

The pattern of activity densities in water and fish from Priest Rapids, Wash., to the mouth of the river near Astoria, Oreg., is shown in figure 4. Although some radioactivity is detectable all the way to Astoria, the values are very small in comparison with those found in the Priest Rapids-Paterson section.

The higher radioactivity values found during this survey were from within the Hanford Reservation, but values of similar magnitude have been reported from other areas during a limited period. Values as high as 2.2×10^{-3} μc./gm. have been found in the muscle of whitefish near Priest Rapids (*2*).

Other river organisms had gross beta activity densities considerably higher than adult fish, but these organisms are not utilized to any extent by humans. Thus, their major significance is in transmitting this activity to other organisms in the food chain. Fish, as well as ducks, geese, and other animals, may consume these organisms.

As previously pointed out, there were no observable, immediate biological effects on any of the river organisms from radioactivity levels in the Columbia River found during these studies. The genetic changes that may occur in aquatic organisms over a long period were beyond the scope of these studies. Some work on the question of genetic changes is being carried out by the General Electric Co. (*3*).

Although certain of the radioactivity levels found in the Columbia River organisms appear high when compared to maximum permissible concentrations in the human body, the maximum permissible concentrations for fish and other aquatic organisms have not been definitely established. Some of the work at the University of Washington (*4–6*) has indicated that the amounts of X-radiation of consequence to certain plankton forms and fish are much larger than quantities permissible for man. The effects of such concentrations in fish eaten by man have not been ascertained.

Public Health Aspects

Because fish and other aquatic organisms concentrate radioactive materials many times above the levels found in water, the use of these organisms for human or animal consumption presents a potential public health problem. Fortunately, most of the radioactivity in fish is from phosphorus–32, a relatively short half-life radioisotope. Natural decay helps in reducing the activity before the fish is eaten. Also, a large portion of the activity is in parts of the fish not used for food, such as scales, bones, and internal organs.

Based on a maximum permissible concentration of 200×10^{-6} μc./ml. and an average daily intake of water of 2,200 ml. (*7*), the maximum permissible intake of phosphorus–32 for man is

0.44 μc. a day. The average level of radioactivity for the highest 13-week period in the muscle of Columbia River game fish, such as bass, was 100 x 10^{-6} μc./gm., and in Columbia River suckers it was 500 x 10^{-6} μc./gm. Salmon and other migratory species do not appear to be important from the standpoint of ingestion of radioactive materials by man since very little of these materials are concentrated in the adults of the species.

Although the amount of fish flesh that man might eat daily before reaching the maximum permissible ingestion of radioactive materials can be computed on the basis of the results of these studies, such a figure would not be too realistic. Few, if any, humans would eat the indicated quantity of fish daily over a lifetime. Moreover, the fish are not eaten immediately after being caught, some time being required for cleaning, cooking, and other preparation. Thus, the actual permissible intake would be greater than the figure computed.

Conclusions

The following major conclusions regarding radioactivity in the Columbia River are drawn from the Public Health Service studies of 1951–53:

1. Low-level beta activity has had no adverse effect upon the numbers and species of aquatic organisms in the Columbia River.

2. The radioactivity levels in plankton and attached algae are directly dependent upon levels in the river water.

3. The radioactivity levels in aquatic animals vary with their metabolic rates (which in turn vary with water temperatures) and with the radioactivity levels of the materials upon which they feed.

4. Migratory species in the Columbia River such as salmon, the adults of which do not feed in fresh waters, have low radioactivity levels at the same time that levels in resident species are high.

5. Radioactive materials are concentrated in all parts of the body of the fish. The activity levels, however, are about 10 times higher in scales, bones, and internal organs than in the edible parts, such as muscle and skin.

6. Since aquatic organisms concentrate specific radioisotopes such as phosphorus–32 many thousand times above the levels in water, the use of these organisms for human or animal consumption presents a potential public health problem. However, to date the levels of radioactivity in the flesh of Columbia River fish are not dangerously high.

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